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Draft Report

A Discussion of Energy Metrics For Cleanrooms

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July 1999

Cleanroom Energy Efficiency Metrics

Introduction

Energy efficiency in cleanroom facilities has historically been quite difficult to quantify. Many facilities were designed with limited measurement capabilities making it difficult to determine the actual end use breakdown for a single system, or the cleanroom portion of a multi-use facility. A typical cleanroom operation includes a large variety of energy intensive systems, including chilled water, recirculation air, exhaust and makeup air, compressed air, deionized water, nitrogen production, process equipment, and others. Each of these systems uses energy, which must be measured and quantified in order to evaluate the efficiency of the system. In addition, the manufacturing processes (tools and equipment) within the cleanroom can have significant direct and indirect impacts on energy use. Herein lies the greatest challenge. Benchmarking of different systems in cleanrooms housing different processes requires development of consistent metrics for quantifying the energy efficiency of each of these widely varying systems.

Why Measure Energy Efficiency?

Not all owners are concerned with the high cost of operating their cleanrooms because they do not consider the cost to be controllable, or they have little or no basis to determine if their facility energy efficiency is good or bad compared to best practices. Before discussing the findings and recommendations for use of energy efficiency metrics it is instructive to discuss their benefits. Metrics in the broadest sense allow a company to evaluate the operation of one facility. Frequently owners are interested in energy cost per unit of production. An example of a metric commonly used for this purpose in the semiconductor industry is energy cost per wafer equivalent (of a certain diameter) produced. This metric considers the energy use of the manufacturing process in addition to the facility usage. This number is used to compare the effectiveness of one factory to other factories making the same product within the same company and to evaluate the performance of the same factory over time. This comparison represents one type of evaluation that is possible with metrics. Measurement of efficiency can also allow many types of comparisons:

1. One type of system to another type of system providing the same benefits either within or outside the company,
2. One type of system to the same type of system at different facilities or at different times in the same facility,
3. A system's actual performance to the manufacturer's or supplier's specifications,
4. A system's actual performance to a known benchmark established within an industry or company,
5. A system to a known "best practice" either within a company or worldwide.

Metrics are most effective when the information is used to improve the relevant systems. Once it is found that a system is not performing optimally, the true benefit of the measurement process is realized once the system is improved. Measurement and comparison alone do not generate benefits unless the information is used to justify and implement effective changes.

What Measurements are Needed to Properly Evaluate System Efficiency?

Perhaps the most challenging part of measuring cleanroom energy efficiency is understanding how best to quantify energy efficiency of so many widely varying systems and processes. The attached table provides a summary of effective metrics that can be used to quantify energy use along with the measurements that are required to develop the metrics. Many of the metrics are commonly used in industry.

Take, for example, chilled water efficiency measured in kW/ton. This standard metric is not only used by industry to rate the chillers at the time of manufacture but also by engineers in the field to verify performance and track the need for maintenance or to identify serious problems with operation. Two cases of facilities that have measured chiller efficiency are illustrative:

Case A: A semiconductor factory with 30,000 ft^2 of cleanroom space was considering buying a new chiller they believed was needed to support a 10,000 ft^2 expansion. The facility already had four 1,000 ton chillers, of which 3 were normally required to run to meet the existing load. The data in figure 1 shows chiller efficiency (in kW/ton, labelled COP) plotted as a function of actual load (in tons, labelled Ton-Cal). The

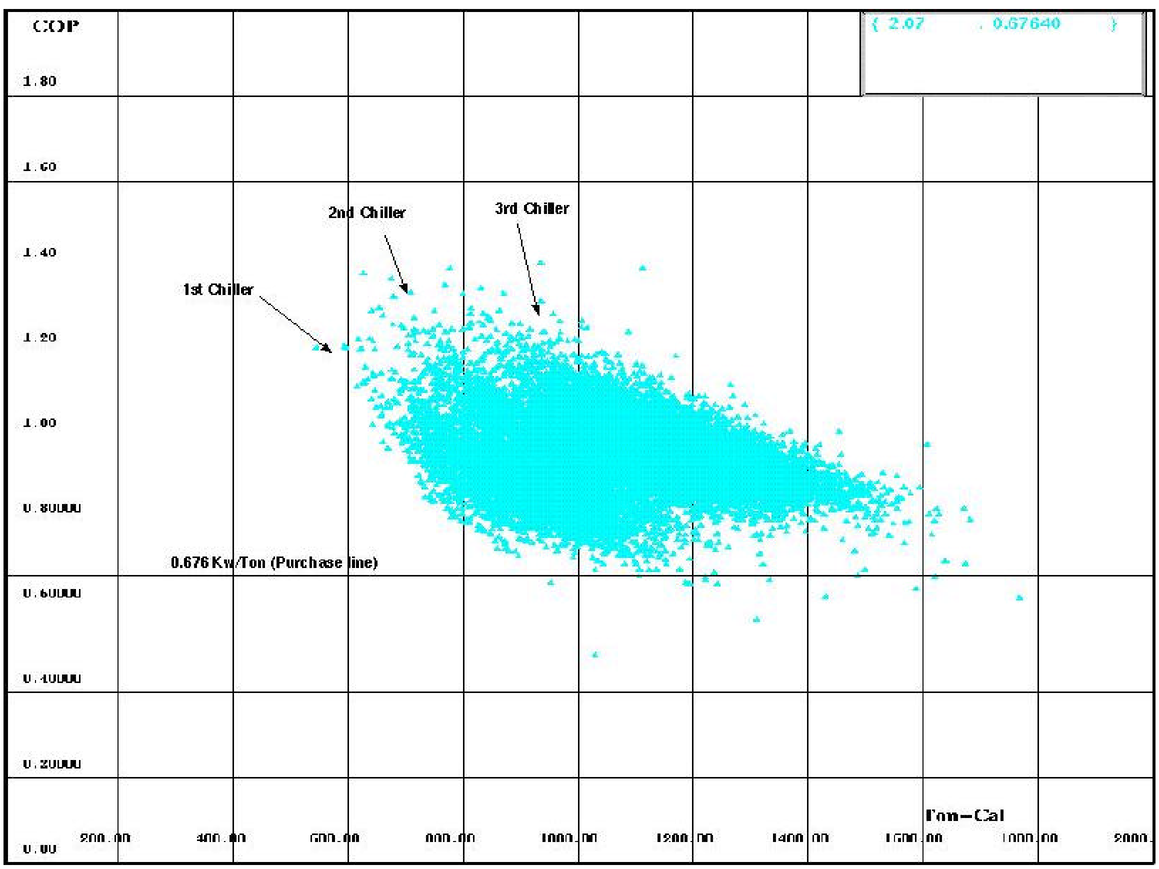

Figure 1: 3,000 tons of chiller capacity providing only about 1,500 tons of cooling

measured efficiency of all of the chillers was consistently above the "purchase line," which is the efficiency claimed by the chiller manufacturer for the chillers at full load. This immediately indicated there was some problem with the system. The data further revealed a peak actual load of about 1,500 tons in the existing facility, which did not even approach the existing 4,000 ton capacity of the system. Three distinct sets of efficiency data were created for the each of the three chillers normally operating during the measurement (they are all overlaid here). This illustrates that, even when additional chillers were brought on-line, only a small improvement in chiller capacity was realized. This led the engineers to the realization that the extra chilled water pumps serving the additional chillers, and not necessarily the chillers, were needed in order to get enough water to the air handlers because the piping system was so poorly designed. Instead of buying a new chiller, the factory spent a fraction of that cost improving their piping layout and was able to provide enough cooling capacity to meet the demands for the expansion and improve the efficiency of their existing cooling operation.

Case B: This 2.5 million ft^2 facility, including predominantly cleanroom area, has a large number of chillers, including five 1,200 ton units. The efficiency data gathered for one of these chillers is shown in figure 2. Note the "purchase point" indicating

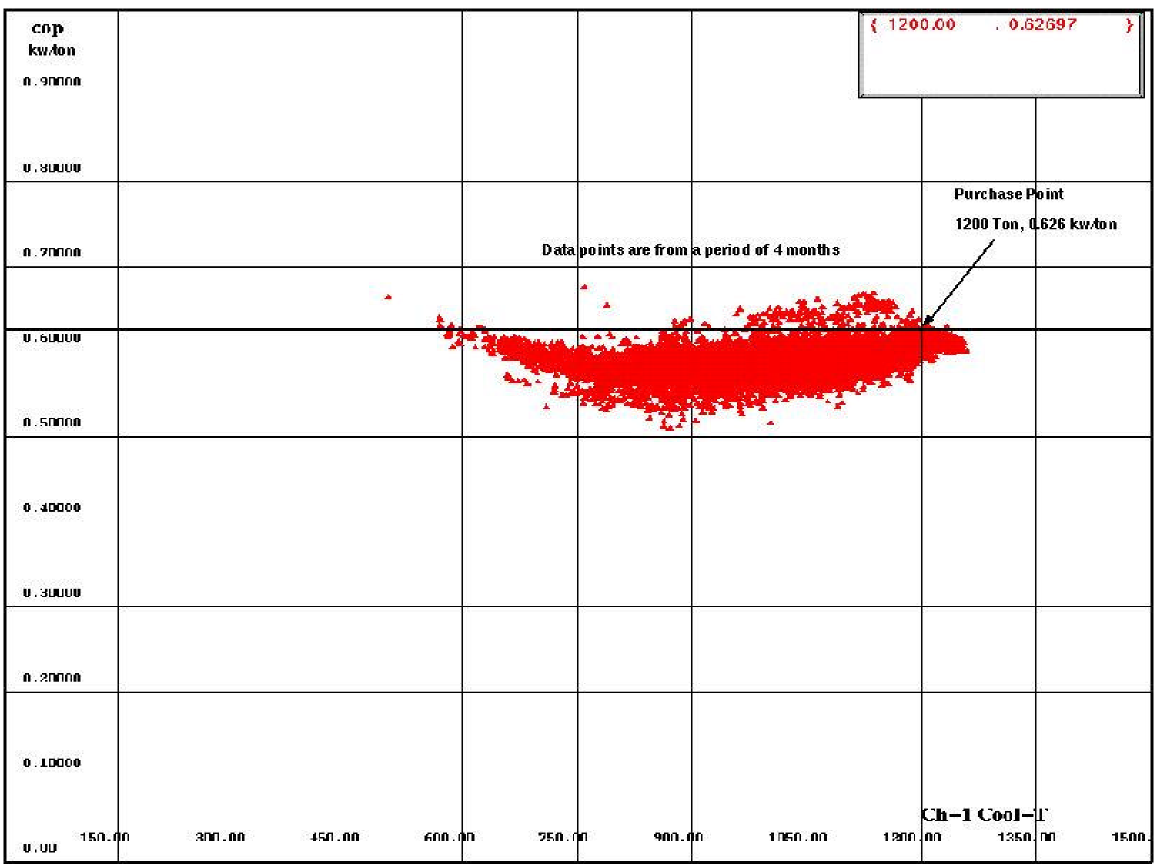

Figure 2: This 1,200 ton chiller typically performs better than its purchase point efficiency

the full load (1,200 ton) efficiency of the chiller at the time of purchase was guaranteed to be 0.626 kW/ton. The data gathered indicates that this chiller is performing precisely as expected - efficiency typically improves slightly for centrifugal chillers operating near full load conditions. This use of chiller efficiency as a metric to gauge performance against manufacturer's specifications has proven that the system is operating correctly, allowing the facility managers and operators to save considerable energy by operating this chiller at all times. It also establishes a benchmark to which all of the other chillers in the plant can be compared – hopefully providing incentive to improve them.

All metrics could be used in this manner if they were accurately measured and reliably reported. Note that the number of measurements needed to calculate the efficiency of a given system is generally quite small – two, three, or four points. What is not clear from the list of required measurements is the difficulty of taking all of these measurements accurately and reliably. This represents one of the many barriers to adequate and useful implementation of cleanroom energy efficiency metrics.

Barriers to Implementation of Energy Efficiency Monitoring

Some of the greatest challenges in the cleanroom industry revolve around advancement of manufacturing technology and improvement of total yield. Neither of these challenges is typically viewed as linked to energy efficiency. This is primarily because the cost of cleanroom operation is often disjointed from its production. This focus is a primary reason for lack of interest in installation of sensors and equipment to measure energy efficiency in a cleanroom facility at the time of construction. Often, there is little thought given to the need to measure energy use and this requirement is lost in the myriad of decisions which must be made to bring a facility on line rapidly. Facility owners are driven to construct cleanrooms in time to get products to market before a competitor or before the product is no longer viable in the quickly evolving marketplace.

This lack of interest or awareness is a primary difficulty behind implementation of energy efficiency in cleanroom facilities. Building engineers frequently complain about not having enough information about the systems under their control to accurately assess their effectiveness. It is quite common for cleanroom facilities to look into the cost of improving their monitoring system after the project is complete. They quickly realize that not only is monitoring equipment quite costly for a meager operations budget, it is extremely difficult to retrofit onto a system that is required to operate 24 hours per day and, for air flow and temperature sensors, must remain clean and sterile (as in most biotech cleanrooms). One solution to this problem is to develop a series of standard measurements (much like the Federal Standard 209E and the soon to be released ISO cleanliness standards) that can be used to standardize energy efficiency measurements and have the necessary metering and instrumentation included during initial construction. The sensors needed to quantify these metrics must be included at the time of system construction, when they add little to the cost of the system, but significantly increase its value during operation.

Agreement on which metrics to use is critical, but perhaps even more critical is how to use the information. Many companies express interest, either publicly or privately, in keeping their production secrets to themselves. Energy efficiency data is often viewed this way because it may reveal some critical bit of information about production that will compromise the small market advantage that a company has in manufacturing its product. Unfortunately, this protective attitude prevents serious inroads toward determining the efficiency of systems currently operating in industry. For this reason, we have generally recommended metrics that are not tied to production. A second advantage to this approach is the ability to compare systems across industries. The attached table provides information, where possible, on the best known practice for a given system. However, it is difficult to understand the significance of these numbers without some sense of the typical practice in industry. Many of the best practice numbers are pulled from a very small, and statistically insignificant, sample of actual facilities.

Industry-wide comparison of systems may never be possible without some type of understanding by the industries that utilize cleanrooms that energy efficiency improvement can be significantly enhanced by sharing and acting on actual performance data. If companies are reluctant to share, action will have to come from within. So, the effectiveness of efficiency metrics may be contingent upon an internal comparison of measurements. Friendly competition is one useful opportunity for a facility and company to improve its energy efficiency. Even for companies that are reluctant to share benchmarking and best practices, it is certain that internal benchmarking comparing system to system, facility to facility, or to verify manufacturers' specified performance will be extremely valuable. Internal comparison of systems will allow a company to benchmark against itself and find the systems and facilities where improvement will be most effective and is most needed. This can be done using the suggested metrics or a company developed set of metrics.

Proposed next steps

We encourage the industries that operate cleanrooms to become active in benchmarking and monitoring their facilities. Additional data from field measurements will help to determine performance improvement. As additional data becomes available, best practices values will emerge. Performance against best practices values may be used to compare like facilities within a company, or they may be used to determine performance against like facilities.

LBNL proposes to collaborate with industry organizations such as Sematech, ASHRAE, and IEST to develop best practices values based upon benchmarking data. We also propose working with individual industry firms to assist in gathering and analyzing benchmark data. Best practices data specific to a firm or a process within a firm would be valuable within the context of the firm, or if the data could be shared with other firms, would help to establish a more robust data set for the industry.